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LONG–TERM METHANOL TEST PROGRAM

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ABSTRACT

A 1988 Corsica was modified to burn M100 to determine the effects of methanol on engine performance and exhaust emissions during long–term use. Engine wear, gasket endurance, emissions, oil consumption, and overall vehicle performance are being monitored for 25,000 miles of operation.

A vehicle performance baseline was established and will be used for comparative purposes during the program. During engine assembly bearing and ring clearances and cam profiles were measured. The engine produced a maximum torque of 200 lbf–ft at 3750 rpm and a maximum power of 160 hp at 4750 rpm during dynamometer testing. The stock 2.8 L gasoline engine is rated at 160 lbf–ft at 3600 rpm and 125 hp at 4500 rpm. The vehicle underwent EPA emissions testing at Southwest Research Institute. The results for THC (0.48 g/mi), CO (0.96 g/mi), and NO_x (0.15 g/mi) are all below ULEV requirements. The unadjusted NMOG was 0.479 g/mi with 0.464 g/mi of alcohol being the primary constitutent. Oil consumption tests were also performed at Southwest Research Institute.

At least 25,000 miles, approximately 1/3 highway and 2/3 city, are being accumulated on the vehicle. Oil samples are taken and analyzed every 3,000 miles. At the completion of the program a second round of emissions and oil consumption tests will be performed at Southwest Research Institute. These results will indicate degradation caused by the long–term use of methanol. The engine will be removed from the vehicle and retested on the engine dynamometer to identify any performance loss. After dynamometer testing, the engine will be disassembled and all fits and clearances measured and the engine gaskets and seals will be analyzed for degradation.

LONG–TERM METHANOL TEST PROGRAM

BACKGROUND AND OBJECTIVE

Methanol, one of the leading alternatives to gasoline as a motor vehicle fuel, has been highlighted in national competitions such as the 1989 SAE Methanol Marathon and the 1990 SAE Methanol Challenge, but little has been done in the area of long–term testing of methanol as a motor vehicle fuel. To address this shortcoming a 1988 Chevrolet Corsica was modified by Texas Tech University to serve as a test bed to determine the long–term effects of methanol on engine and emission systems performance. The vehicle was initially modified to operate on M85 for the competitions; it has been further modified for M100 as a part of the long–term test program.

The objective of this project is to determine the effects of methanol fuel on engine performance and exhaust emissions during long–term use. Engine wear, gasket performance, fuel economy, emissions levels, oil consumption and overall vehicle performance are being monitored over 25,000 to 30,000 miles of vehicle operation. To achieve these objectives a vehicle performance baseline was established initially and will be used for comparative purposes during the program. All significant engine dimensions and clearances were documented, power and torque were measured on an engine dynamometer, tailpipe emissions were measured, and oil consumption tests were run. The vehicle will be driven for at least 25,000 miles. After sufficient mileage has been accumulated, all performance and emissions measurements will be repeated for comparison with the baseline and the engine will be torn down for inspection.

VEHICLE MODIFICATIONS

The Corsica was initially modified to operate on M85 for the SAE Methanol Marathon/Challenge competitions [4]. The vehicle won 2nd place overall in the 1990 Methanol Challenge, placing first in endurance fuel economy, second in acceleration, and demonstrating excellent emissions and maneuverability. Table 1 summarizes the major event rankings for the Texas Tech Corsica.

A methanol compatible fuel system (tank, pump, lines, fuel rail, and injectors supplied by GM) was installed for the SAE competitions. GM delivered the Corsica with a computer interface which allows modifications to the engine control maps during engine operation.

The engine stroke was increased to take advantage of the increased amount of exhaust product and slower burning charac-

Table 1 Results of Texas Tech entry in 1990 SAE Methanol Challenge

2nd Place Overall			
1st Place Endurance Fuel Economy			
2nd Place Acceleration			
FTP Emissions Results (g/mi)			
HC	0.04	NO_x	0.71
NMHC	0.03	CH_3OH	0.29
CO	0.60	OMHCE	0.16
FTP Fuel Economy Results (Miles per gallon gasoline equivalent)			
City	21.6		
Highway	41.0		
55/45 city/Highway	27.4		

teristics of methanol. To insure good fuel economy the bore was decreased to maintain a displacement of 2.8 liters. The crankshaft from a 1990 3.1 liter GM V–6 engine was used to achieve a stroke increase from 2.99 inches to 3.31 inches. Because methanol has a higher octane rating than gasoline, the compression ratio was increased to 11.7:1 by installing custom flat top pistons with a centered pin–bore. The piston material contains a high silicon content for low coefficient of thermal expansion, good wear resistance and high–temperature strength. The top piston ring was changed to a chrome ring to maximize the amount of heat retained in the combustion chamber and enhance fuel vaporization. The oil ring was also changed to reduce friction. A custom camshaft was employed to compensate for the slow burning characteristics of methanol. The lobe centers and duration were changed to allow a longer burn time during the power stroke. Roller tip rocker arms were used to reduce friction and valve guide wear. To compensate for the increase in exhaust flow a larger 2 1/4–inch diameter exhaust pipe was used between the exhaust manifold and the catalytic converter and from the catalytic converter back a 2 1/2–inch diameter pipe was used. Allied–Signal, Inc., Tulsa, Oklahoma, provided specially designed light–off and main catalysts to control exhaust emissions. The light–off converter is located near the exhaust manifold in order to reach operating temperature as quickly as possible after engine start. Heated air from around the exhaust manifold is supplied to the air cleaner at temperatures below 85°F to enhance cold–starting and driveability.

To increase fuel economy the 5th gear ratio was lowered from 0.72:1 to 0.603:1. This change resulted in a decrease in engine speed at 60 mph from 2200 to 1875 rpm which takes advantage of the increased torque produced by the engine. To prevent body roll in tight cornering a larger sway bar and gas shocks were installed at the rear. These additions provided greater stability to the vehicle.

At the start of the long–term project, the engine was removed from the vehicle and completely dissembled. The cylinder bores were honed, valve and valve seats were lapped, crankshaft journals were polished, and all gaskets, seals, bearings, and piston rings were replaced. Detailed measurements of significant engine dimensions and clearances were made and documented. Tables 2 and 3 present shortblock and cylinder head measurement data. Camshaft data is included in Table 4.

ENGINE PERFORMANCE

After the engine was reassembled, it was tested on a Super–Flow dynamometer to determine performance at peak and road loads. Corrected power and torque curves for the engine are presented in Figures 1 and 2. Data from two runs on the dynamometer are shown. The engine produced a maximum torque of 200 lbf–ft at 3750 rpm and maximum power of approximately 160 hp at 5000 rpm. GM advertises the torque and power output of the stock 2.8 L engine on gasoline as 160 lbf–ft at 3600 rpm and 125 hp at 4500 rpm. These points are shown on the curves for reference. Thus, the test engine running on M100 provides a 25% increase in maximum torque and a 28% increase in maximum power over the stock engine on gasoline.

CALIBRATION AND EMISSIONS

After the engine was installed in the Corsica, chassis dynamometer testing was accomplished for engine/vehicle final calibration and performance evaluation. Rich conditions under deceleration were experienced and could not be corrected due lack of ECM deceleration table addresses. Thus, the vehicle experiences a slight idle instability after deceleration. Engine starting is acceptable at temperatures above 20°C. Starts at lower temperatures after a cold soak require the use of a starting fluid. Installation of a block heater to augment starting during the winter months is planned.

The vehicle was driven to Southwest Research Institute (SRI) in San Antonio, Texas, for full Environmental Protection Agency (EPA) Federal Test Procedure (FTP) emissions testing. The emission test results were very encouraging with the vehicle meeting ULEV standards for all components except NMOG. The NMOG value may be within ULEV as well, but a RAF for M100 could not be obtained and thus it could not be corrected. Emission results are summarized in Table 5.

FUEL ECONOMY

Fuel economy was measured during the FTP test and economy for typical intercity

Table 2 Shortblock measurements

Cylinder Block						
Cylinder bore (in)	Cyl 1	Cyl 2	Cly 3	Cyl 4	Cyl 5	Cyl 6
Top	3.3303	3.3309	3.3303	3.3305	3.3305	3.3305
Bottom	3.3306	3.3309	3.3306	3.3312	3.3306	3.3309
Main bore (in)	2.847	all ± 0.0005	**Deck height** (in)		7.391	all ± 0.001
Deck milled (in)	0.040					
Connecting Rods						
Bore (in)	2.125	all ± 0.0005	**Mass** (g)		440	
Length (in)	5.70	all ± 0.0005				
Pistons, Pins, and Rings						
Piston Diameter (in)		all ± 0.001	**Ring land clearance** (in)			all ± 0.0005
Top		3.3225	Top			0.0022
Middle		3.2241	Middle			0.0015
Bottom		3.3264				
Piston mass (g)		329	**Piston height** (in)			1.416
Piston pin mass (g)		122	**Pin to bore clearance** (in)			0.0008
Piston ring gap (in)		all ± 0.0005	**Piston ring mass** (g)			39
Top		0.0135	**Oil ring tension (pull)** (lbf)			11.5–12
Middle		0.0085				
Crankshaft						
Rod journals (in)	1.9983	all ± 0.0005	**Main journals** (in)		2.6468	all ± 0.0005
Stroke (in)	3.310	all ± 0.0003				
Rod bearings			Main bearings			
Thickness (in)		all ± 0.0005	**Thickness** (in)			all ± 0.0005
Min (at center)		0.0595	Min (at center)			0.0902
Max (where halves meet)		0.0622	Max (where halves meet)			0.0929
Avg clearance (in)		0.002	**Avg clearance** (in)			0.002
Mass (g)		33				

driving was estimated during trips to San Antonio. FTP city mileage was measured to be 9.91 mpg (20 mpeg) and highway mileage was estimated to be 16 mpg (33 mpeg). The highway fuel economy rating for the stock gasoline vehicle is 29 mpg.

OIL CONSUMPTION TESTING

The vehicle was returned to SRI in San Antonio during March 1993 for oil consumption testing 3]. The oil consumption rate was determined with an on-line SO_2 tracer test procedure while the vehicle was run through the FTP Urban driving cycle on a chassis dynamometer [1 and 2]. Transient tests were run from both cold and hot starts. In addition, several steady state tests were conducted.

Test results reflect an oil consumption rate that is somewhat higher than typical gasoline fueled vehicles that have been tested by SRI. This may be related to the use of methanol or possibly the lack of engine operating time and incomplete seating of the piston rings. At the time of the oil consumption tests, the engine had accumu-

Table 3 Cylinder head measurements

	Cylinder 1		Cylinder 3		Cylinder 5	
	Intake	Exhaust	Intake	Exhaust	Intake	Exhaust
Valve Stem Dia (in)	0.3131	0.3138	0.3139	0.3136	0.3138	0.3132
Valve Guide Dia (in)	0.3150	0.3151	0.3151	0.3151	0.3149	0.3152
Installed Height (in)	1.720	1.720	1.710	1.720	1.710	1.715
Shim Thickness (in)	0.075	0.075	0.060	0.075	0.060	0.075
Spring Coil Bind (in)	1.19 ±0.3	1.19 ±0.3	1.19 ±0.3	1.19 ±0.3	1.19 ±0.3	1.19 ±0.3
Spring Pressure (lbf)	95 ±5	95 ±5	95 ±5	95 ±5	95 ±5	95 ±5
Retainer to Seal (in)	~0.540	~0.540	~0.540	~0.540	~0.540	~0.540
Seal Thickness (in)	~ 0.160	~ 0.160	~ 0.160	~ 0.160	~ 0.160	~ 0.160
Comb Chamber Vol (cc)	26.6		26.6		26.6	
	Cylinder 2		Cylinder 4		Cylinder 4	
	Intake	Exhaust	Intake	Exhaust	Intake	Exhaust
Valve Stem Dia (in)	0.3135	0.3137	0.3138	0.3138	0.3138	0.3138
Valve Guide Dia (in)	0.3152	0.3152	0.3151	0.3150	0.3150	0.3150
Installed Height (in)	1.730	1.725	1.720	1.715	1.715	1.715
Shim Thickness (in)	0.075	0.075	0.075	0.075	0.060	0.075
Spring Coil Bind (in)	1.19 ±0.3	1.19 ±0.3	1.19 ±0.3	1.19 ±0.3	1.19 ±0.3	1.19 ±0.3
Spring Pressure (lbf)	95 ±5	95 ±5	95 ±5	95 ±5	95 ±5	95 ±5
Retainer to Seal (in)	~0.540	~0.540	~0.540	~0.540	~0.540	~0.540
Seal Thickness (in)	~ 0.160	~ 0.160	~ 0.160	~ 0.160	~ 0.160	~ 0.160
Comb Chamber Vol (cc)	26.6		27.2		26.8	

Intake Valve Face Diameter	(in)	1.73	Exhaust Valve Face Diameter	(in)	1.60
Gasket Surface Milled	(in)	0.040	Head Gasket Thickness	(in)	0.068
Total Swept Volume	(cc)	472.38	Head Gasket Volume	(cc)	11.56
Compression Ratio		11.72			

Table 4 Camshaft measurements

	Cyl 1	Cyl 2	Cly 3	Cyl 4	Cyl 5	Cyl 6	Avg	Var (±)
Intake & Exhaust								
Lobe Center Sep (Cam Deg)	111.1	111.0	110.9	110.8	111.1	111.1	**111.0**	0.3
Valve Overlap (Crank Deg)	−27.6	−27.5	−27.2	−27.2	−27.8	−28.0	**−27.5**	0.4
Intake								
Valve Openting (Deg BTDC)	−7.8	−7.8	−7.6	−7.6	−7.9	−8.0	**−7.8**	0.2
Lobe Center (Deg ATDC)	104.6	104.5	104.4	104.3	104.5	104.5	**104.5**	0.1
Valve Closure (Deg ABDC)	22.5	22.5	22.2	22.2	22.2	22.1	**22.3**	0.2
Duration (Crank Deg)	194.7	194.7	194.6	194.6	194.3	194.1	**194.5**	0.3
Max Cam Lift (in)	0.26031	0.26028	0.25992	0.25988	.025854	0.25850	**0.25957**	0.00091
Net Valve Lift (in)	0.39047	0.39041	0.38988	0.38982	0.38781	0.38776	**0.38936**	0.00136
Lobe *Area* (in−Deg)	18.61	18.64	18.63	18.61	18.47	18.45	**18.57**	0.09
Exhaust								
Valve Openting (Deg BBDC)	34.1	34.2	33.9	34.0	34.1	34.1	**34.1**	0.1
Lobe Center (Deg BTDC)	117.5	117.5	117.4	117.3	117.6	117.5	**117.5**	0.1
Valve Closure (Deg ATDC)	−19.8	−19.8	−19.6	−19.6	−19.9	−20.0	**−19.8**	0.2
Duration (Crank Deg)	194.3	194.4	194.3	194.4	194.2	194.0	**194.3**	0.2
Max Cam Lift (in)	0.25933	0.25917	0.25921	0.25906	0.25902	0.25906	**0.25914**	0.00016
Net Valve Lift (in)	0.38900	0.38876	0.38882	0.38858	0.38852	0.38858	**0.38871**	0.00024
Lobe *Area* (in−Deg)	18.47	18.54	18.5	18.53	18.46	18.44	**18.49**	0.05

Intake		**Exhaust**	
Rocker Ratio	1.5	Rocker Ratio	1.5
Hot Lash (in)	0.0	Hot Lash (in)	0.0
Cam Advance (Crank Deg)	6	Checking Height (in)	0.05

Cam ground by Cam Motion

Cam profile analysis made with PC based Cam Doctor

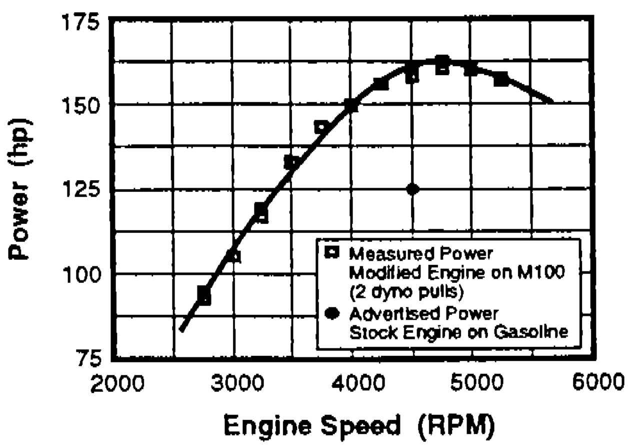

Figure 1 Engine power output on M100

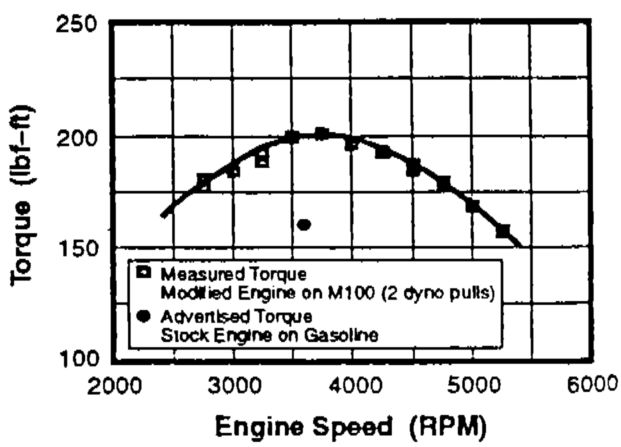

Figure 2 Engine torque output on M100

Table 5 Emissions results (M100)

Constituent	SRI Test (grm/mi)	ULEV (grm/mi)	Constituent	SRI Test (grm/mi)	ULEV (grm/mi)
THC	0.48	—	Acrolein	0.0000	—
CO	0.96	1.7	Acetone	0.0012	—
NO_x	0.15	0.2	Propionald	0.0000	—
CH_4	0.035	—	Crotonald	0.0000	—
NMHC	0.011	—	Isobutyr + MEK	0.00018	—
Carbonyl	0.005	—	Benzaldehyde	0.0000	—
Alcohol	0.464	—	Hexanaldehyde	0.0000	—
NMOG	0.479*	0.04	Methanol	0.464	—
Formaldehyde	0.003	0.008	Ethanol	0.0000	—
Acetaldhyde	0.0002	—	* The RAF for M100 was unknown—this value uncorrected.		

lated approximately 2,000 miles since reassembly. Figures 3 and 4 show a comparison of the first 1200 sec of the cold start and hot start transient tests. Note that the oil consumption rate for the cold start is lower for about 800 seconds while the engine is warming to typical operating temperature. Once normal operating temperature (200°F) is reached, the oil consumption rates for both the hot start and cold start runs are similar. Increases in load (accelerations) produce spikes in the oil consumption rate, whereas, constant load and reducing load conditions produce relatively lower rates of oil consumption.

Figure 5 presents the results of a steady state run at 2675 rpm with the transmission in 4th gear. There is a distinct correlation between the coolant temperature and the oil consumption rate. This relationship is probably due to the change in temperature of the oil on the cylinder walls and around the valve guides as the coolant temperature cycles. It is apparent that the oil consumption rate is very sensitive to the coolant temperature which is directly related to the oil temperature in the areas where the oil can enter the cylinder. Engine clearances in these areas may also be cycling with the coolant temperature.

The excellent results achieved during the emissions testing in January would reasonably have been expected to correlate with low oil consumption. This anomaly is not understood at present but SRI emissions and oil consumption test personnel have been requested to review the results of these two tests to see if any conclusions can be drawn. This is an area in which additional information can be obtained during the oil consumption test at the conclusion of the program, after the vehicle has accumulated 25,000 miles of city and highway driving.

MILEAGE ACCUMULATION

The vehicle has been driven in and around Lubbock by project personnel and others. One of the departmental secretaries has used the vehicle to commute to work for about a month. The vehicle is fueled from 55 gal drums of methanol provided by Air Products and Chemicals. Intercity driving and refueling is accomplished by towing a small trailer with 1 or 2 drums of methanol on–board. By carrying approximately 100 gal of fuel on the trailer, it has been possible to

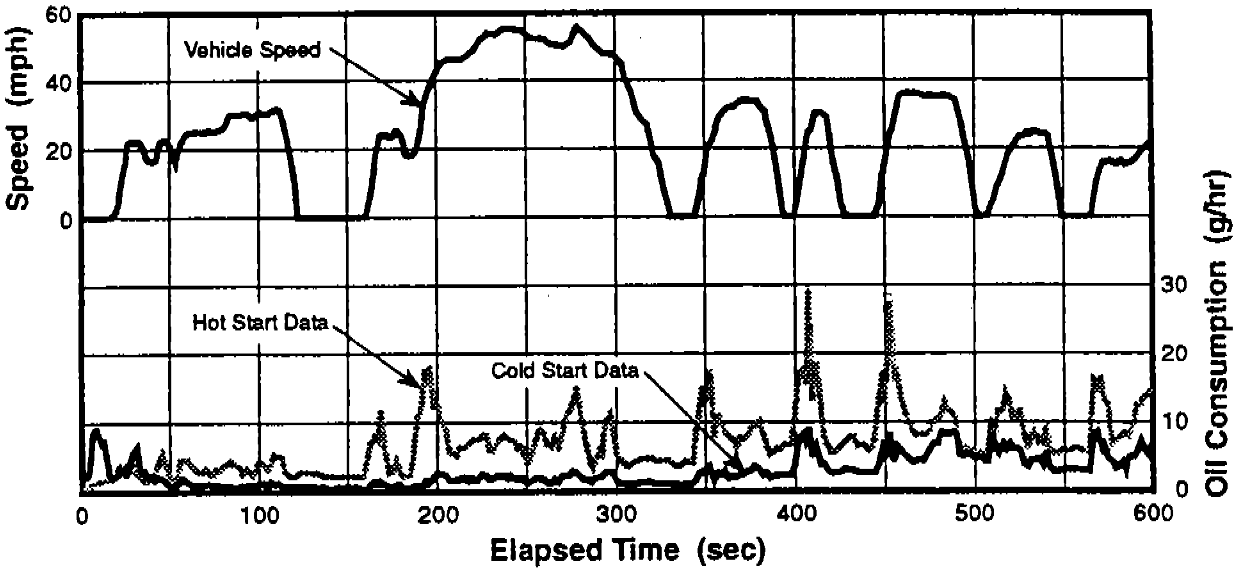

Figure 3 Oil Consumption during transient tests 0 to 600 sec

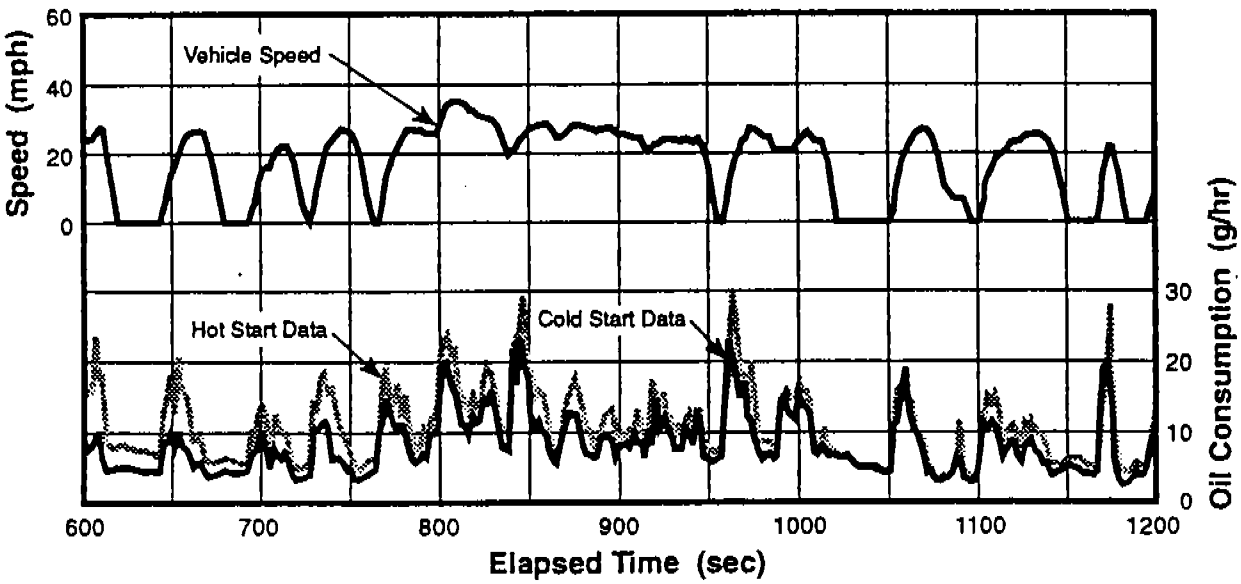

Figure 4 Oil Consumption during transient tests 600 to 1200 sec

make round trips to Dallas, Austin, and San Antonio. To date approximately 7,000 miles have been accumulated on the vehicle. This mileage is roughly evenly divided between city and highway driving conditions.

The vehicle was exhibited during Texas 4th Annual Alternative Fuels Market Fair and Symposium in Austin on June 6–8, 1993. It was also driven in the Lubbock 4th of July parade. The vehicle will continue to be driven until at least 25,000 miles have been accumulated.

Very few problems have been experienced with the vehicle during the mileage accumulation. The hydraulic clutch slave cylinder failed during a full throttle acceleration drive and the mass air flow sensor was replaced after the mounting boss broke.

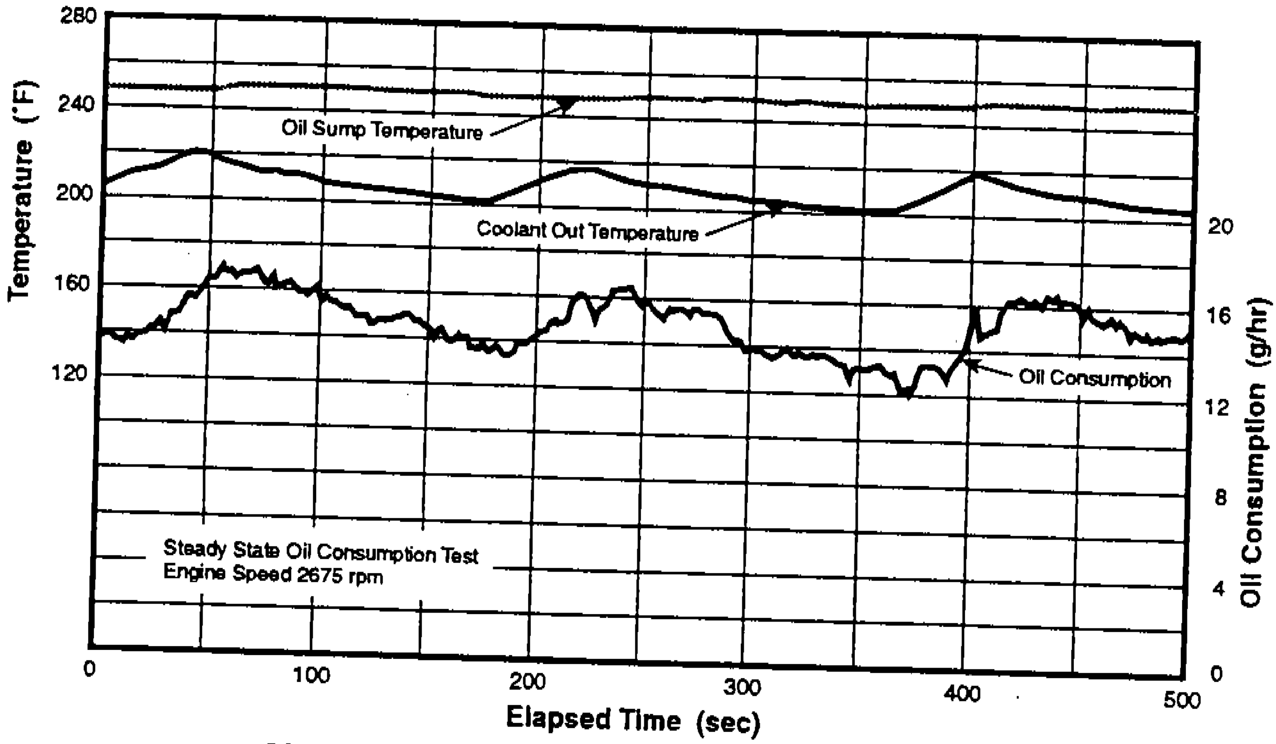

Figure 5 Oil Consumption during steady state test

CONCLUSIONS

The Corsica has been modified to operate on M100 and all baseline measurements and performance data has been collected and documented. The engine power output is approximately 28% higher than the stock 2.8 L engine. Baseline emissions data are very good; the engine is below ULEV standards in all categories except NMOG. The oil consumption data shows a slightly higher rate of oil consumption than typical gasoline fueled engines. Mileage is currently being accumulated on the vehicle. When 25,000 to 30,000 miles are accumulated, the vehicle will be retested for emissions, oil consumption, and power and the engine will be torn down to determine wear.

ACKNOWLEDGEMENTS

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